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A Fault Diagnosis in Aluminium Honeycomb Structure using Vibration Technique & FEM Approach

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Abstract:- *Honeycomb sandwich structures have been widely used in the manufacture of the aerospace structures due to their lightweight, high bending stiffness and strength under distributed loads in addition to their good energy-absorbing capacity. Damages present a serious threat to the performance of machines. For this reason, methods making detection and localization of damages have been the subject of many researches. In the present study we have prepared the same structure and created artificial damage in between the interface of core and faceplate and also in the core of sandwich beam to simulate core–faceplate debonding and core crushing, respectively. Natural frequency is used to identify the defect in the honeycomb structure using the vibration analysis for the damage detection in the Aluminium plate of the specific size and the results are obtained with the help of the FFT Analyzer. The results obtained by experimentation are compared with the FEM i.e. ANSYS result. In this work first three frequencies obtained for the damaged structure and the healthy structure are recorded and then normalized frequencies are used to plot the contour plots using Design Expert software. The intersection of the contour lines of all three mode shapes gives the location of the damage. This will be much helpful to have the prior notice of the serious accidents in the aviation like spacecraft's, marine applications where this type of structure is to be used. So the main objective of this thesis is to detect the damage in the Honeycomb Structure which artificially prepared during manufacturing with the help of the Experimentation and FEM Analysis will help to know the position of unknown damage.*

Keywords: **Aluminium Honeycomb Structure, Damage Detection, FFT Analyzer.**

1 INTRODUCTION

Honeycomb sandwich structures have wide application in the manufacture of the aerospace structures due to their high bending stiffness, lightweight and strength under distributed loads with good energy-absorbing capacity. (Wahyu Lestari, et al, 2005; A.Boudjemai, et al, 2012). Damage in any type of structure is a serious problem to the machines performance. Due to this reason, methods making localization and detection of damages have been the research subject for many researchers. Vibration results in dynamic stresses and strains in the structures, which can cause fatigue and failure in it, also the fretting corrosion between contacting elements and noise in the environment; and can, impair the function and life of the blade itself. In order to predict the natural frequencies, it is necessary to analyze the vibration and the response to the required excitation. Structural damage detection can be classified as global and local-damage detection. Vibration-based structural damage detection is new and emerging area of research within SHM and its development can be divided into traditional and modern type. In traditional types of damage detection methods mechanical characteristics of structures like natural frequencies, modal damping, modal shapes, utilized. However, these kinds of method are not convenient for online detection of structures since all require experimental modal analysis or transfer function measure. The modern-type such as techniques incorporating vibration signatures for analysis refer to the damage detection methods based on response signals acquired from excitation of structures. Its advantages can be summarized as: (1) compared with the traditional type techniques, it is less dependent on experiments. Vibration responses at few points on the structure are sufficient for damage detection. (2) Using the more modern-type techniques, smaller structural damage can be detected by the construction and extraction of better characteristic information from structural dynamic response signals. From the modern methods for structural damage detection, some of them include Wavelet analysis, Genetic algorithm (GA) and Artificial Neural Network (ANN).

Generally vibration theory is correlated with the modal parameters like frequency, mode shapes and damping. These physical systems consist of the structure physical properties (mass, stiffness, and damping). These model parameters are the solutions of the homogeneous part of the differential equation of motion of a physical model expressed in terms of its mass, damping, stiffness, acceleration, velocity, and displacement.

2. LITERATURE REVIEW

Wahyu Lestari et.al [1] has performed an experimental damage identification procedure based on structural dynamic response and using smart sensors is conducted. Damage identification is estimated from comparison of dynamic response of healthy and damaged FRP sandwich beams. Correspondingly, based on the relationship between the changes of mechanical properties and the related changes of the dynamic responses (the curvature mode shapes in this study), damage magnitude is quantified. Artificial damage is created between the interface of core and face plate and also in the core of sandwich beam to simulate core face plate debonding and core crushing, respectively. Using piezoelectric smart sensors, dynamic responses data collected and dynamic characteristics of the sandwich structure are extracted, from which the location and magnitude of the damages are evaluated.

A.Boudjemai et.al[2] have performed a multidisciplinary design and analysis (MDA) of honeycomb panels used in the satellites structural design. In the present work, detailed finite element models for honeycomb panels are developed and analysed. Experimental tests were carried out on a honeycomb specimen of which the goal is to compare the previous modal analysis made by the finite element method as well as the existing equivalent approached. The various results obtained in this paper are promising and shows the geometry parameters and the type of material have an effect on the value of the honeycomb plate modal frequency.

Chih-Chieh Chang et.al [3] Chen have presented a technique for structure damage detection based on spatial wavelet analysis. Many damage detection methods require modal properties after and before damage. This method only need spatially distributed signals (e.g. the displacements / mode shapes) of the rectangular plate after damage. It is observed that distributions of the wavelet coefficient scan identify the damage position of rectangular plate by showing a peak at the position of the damage.

J.T. Kim et.al [4] have presented practical non-destructively method of localization of crack using natural frequencies in a structure. A crack detection algorithm to locate the crack using natural frequencies is outlined. The feasibility and practicality id checked for several crack in the structure and observed that size of crack can be estimated with the relatively small error.

Missou Lakhdar et.al [5] have studied the damage detection in a composite structure by vibration analysis. This work focuses on damage detection using vibration analysis to understand the dynamic response of the composite structure under damage and those results are compared with those predicted by numerical models and the effectiveness is checked..

3. PROBLEM STATEMENT

To detect the damage in the Honeycomb Structure sandwich plate by using vibration analysis utilizing FFT Analyzer for avoiding the serious hazards and improvement of the life of the components and determination the Bending strength.

4 . OBJECTIVES

1) An experimental damage identification procedure based on structural dynamic responses using FFT Analyzer is conducted on the healthy and damaged honeycomb structure plate.
2) Damage identification is estimated from comparison of dynamic responses of healthy and damaged sandwich plate. Also the obtained results are compared with ANSYS results.
3) Finally damage is detected in the plate with its location magnitude and depth to avoid the future hazards of the plate when it is used in the preferred application like aero plane or helicopter blades or in marine applications.

5. METHODOLOGY

The relationship between the changes of mechanical properties & the related changes of dynamic responses (i.e., Frequency response functions in this study), damage magnitude and location is quantified. The sandwich beams are made of Aluminium, and the core consists of the corrugated cells in a Hexagonal configuration. Artificial damage is created between the interface of core and face plate and also in the core of sandwich beam to simulate core–faceplate debonding and core crushing, respectively. The honeycomb structure plate is used as the specimen in whom damage is analyzed. Using accelerometer, dynamic responses data is collected and dynamic characteristics of the sandwich structure are extracted, from which the location & magnitude of the damage is evaluated. As demonstrated in this study, the present dynamic response based procedure using FFT Analyzer is effectively used to assess damage and monitor structural health of FRP honeycomb sandwich structures. On the basis of first three natural frequencies obtained from the FFT analyzer the contour plots are plotted. The contour plots are combined for first natural frequencies which are obtained from the Design Expert software. The normalized frequencies are used for location of the crack in the plate. Finally the results obtained from Experimentation are compared with the FEM results.

5.1 HONEYCOMB THEORY

The honeycomb sandwich structure is designed on the applications like the core, adhesive and the face plate. Again the criteria of designing may be the mechanical properties of the constituents but price of the structure is another parameter may be considered for designing due others several factors of the magnitude. It is also used in skin frame design. A honeycomb sandwich structure consists of two thin face sheets attached to both sides of a lightweight core (see figure1)

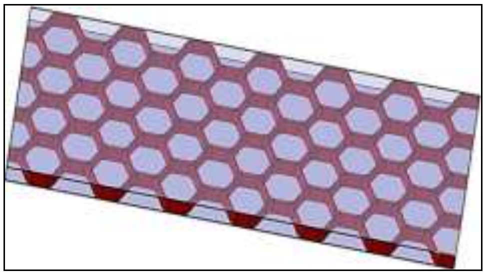

Fig-1: Honeycomb Sandwich Structure

The sandwich structures are usually subjected to the axial loads, bending moments and shear stresses while the core may carry flexural shear. Sandwich structures may fail due to concentration of the normal local stress due to heterogeneous structured core. Sandwich panel face sheets are commonly fabricated using aluminium or graphite/epoxy composite panels. The core is fabricated using a honeycomb or aluminium foam construction.

5.2 MATERIAL OF STRUCTURE

The material for the honeycomb structure should be selected such that it should have high strength and low weight. So materials are like Aluminium or Carbon Epoxy composite. The material for our test is of Aluminium and its composition with the detail dimension of plate is as given below:

TABLE-1: COMPOSITION OF ALUMINIUM

Al	Rem
Mg	0.09
Cu	0.084
Si	0.41
Fe	0.67
Mn	0.1
Ni	0.1
Zn	0.1
Pb	0.05
Sn	0.01
Ti	0.2

TABLE-2: MATERIAL PROPERTIES OF ALUMINIUM

Material property	Value
Density	2700 kg/m3
Young's Modulus	71070 MPa
Yield Strength	268 MPa
Compressive Strength	2.5 MPa
Compressive Modulus	540 Mpa
Tensile Strength	367 Mpa

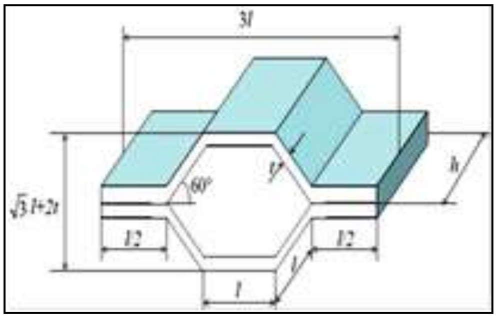

Fig-2: Single cell of Honeycomb plate

5.3 DEFECTS IN HONEYCOMB STRUCTURE

Generally the defects or the damage emerges in the sandwich honeycomb structures are due to the skin problems, core defects or due to the delamination in the core and the skin. So the practical types of the damages in honeycomb structure are as follows:

5.4 DEBONDING OF HONEYCOMB STRUCTURE

In this type of defect of honeycomb structure the contact between the skin plate & the honeycomb core cut and then at that position the section become weak and there is irregular frequency distribution finally results in crack in the structure. This generally occurs due to intra cell buckling of panel buckling.

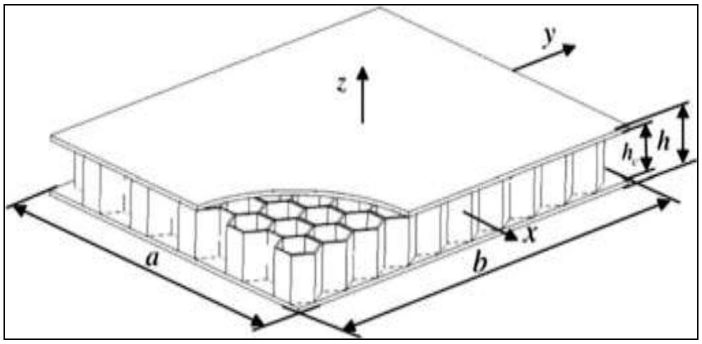

Fig-3: Geometrical model of honeycomb plate

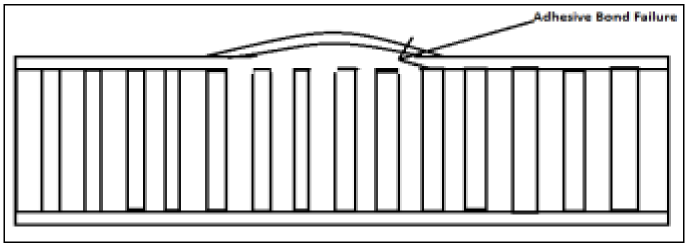

Fig-4: Debonding in honeycomb plate

5.5 Delamination in Honeycomb structure

This type defect is incurred due the change in the temperature conditions and the impact load on the specific point. Local compression may lead to the delamination of the skin or adhesive contact between the core and the adhesive as shown in fig 5

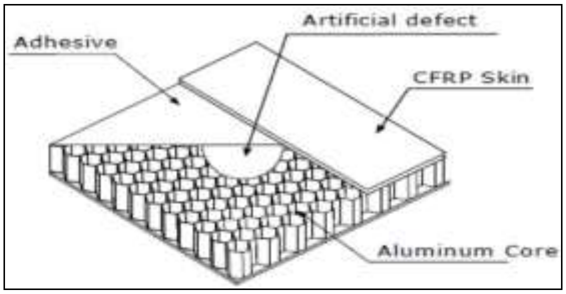

Fig-5: Artificial Delamination in honeycomb plate

5.6 Core crushing in Honeycomb structure

In this type of damage in honeycomb structure the sudden impact may result in the inner part of the honeycomb to be damaged by getting crushed at some parts. Maximum deflection, local compression and shear wrinkling mark result in the crushed core.

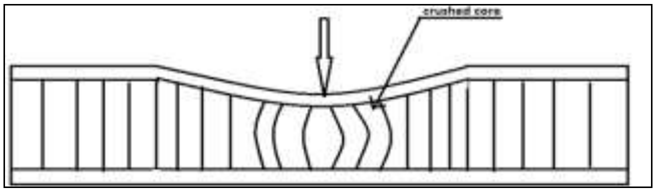

Fig-6: Core crushing in honeycomb plate

VI. FINITE ELEMENT ANALYSIS

The finite element method has become a powerful tool for numerical solution of a wide range of engineering problems. The application range from deformation and stress analysis of automobile, aircraft, buildings and bridge structures to field analysis of heat flux, fluid flow, magnetic flux and other flow problems. With the advance in computer technology and CAD system, complex problems can be modeled with relative ease. Several alternative configurations can be tested on a computer.

6 Modeling

The three dimensional model of the plate with actual dimensions was prepared in CATIA V5 software as shown in figure 7 The model was prepared using solid brick elements. Similarly all models were prepared in the same software. After modeling, same model is being converted to the IGES (Initial Graphics Data Exchange Format) using IGES translator in CATIA V5. These all models were further imported in ANSYS 14.0 for analysis. All three parts like Honeycomb Structure and the skin plates were separately modeled and then the assembly was prepared.

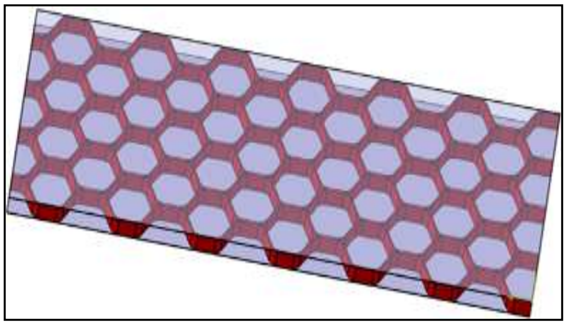

Fig -7: Modeling of honeycomb structure plate.

6.1 Meshing

Meshing is first step to do the analysis of any component. It can be done in ANSYS, or can be done for complex geometry of the component using HYPERMESH (software exclusive for meshing).

Meshing generally falls in two categories depending on geometry of the element. For 3D machine element of regular shape, solid meshing is sufficient, but for irregular geometries we have to first use surface meshing and then solid meshing. For meshing the solid model is imported from CATIA V5 to ANSYS. The selection of which element to use in the problem to be analyzed is important. The meshed model is shown in the figure

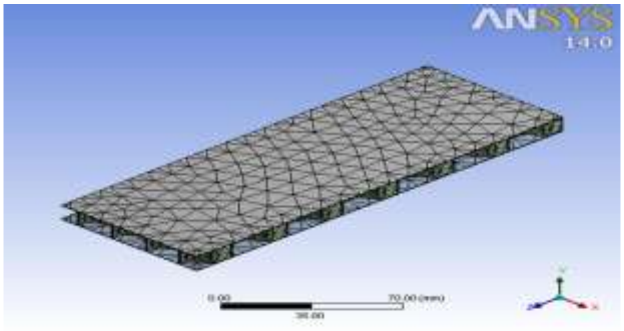

Fig -8: Meshed Model of honeycomb structure plate

6.2 Boundary conditions and loading

After completion of the finite element model, the boundary conditions should be applied. The analysis is carried out in cantilever type conditions of the plate. Since the condition is considered to be equivalent to the application of aero plane wings, which are in cantilever conditions. Now the model is ready for eigenvalue analysis as the Eigen values gives the modal frequencies an Eigen vectors gives the mode shapes, Eigen value analysis of various model is carried out. The theoretical analysis for the structure was carried out using FEM method and modal analysis was done. The fig shows the damaged honeycomb structure with open crack and crushed core for X= 100mm and Y= 15mm having total length of 200mm. Similarly the first three natural frequency for the each damaged plate was recorded including the healthy honeycomb structure plate and tabulated as shown in table 6.1 which shows the respective crack position X and Y an the respective first three natural frequency for the each plate.

TABLE-3: THEORETICAL FEM RESULT

Case	**Crack position X**	**Crack position Y**	**Frequencies (Hz)**		
	mm	**mm**	**f1**	**f2**	**f3**
1	Healthy		282.07	1672.8	4353.6
2	100	15	280.57	1641.5	4234.2
3	100	30	280.6	1643.6	4255.5
4	100	45	280.85	1648.3	4276.7
5	120	15	281.77	1643.9	4252.9
6	120	30	282.09	1645.9	4276.4
7	120	45	281.74	1644.1	4274.1
8	140	15	282.94	1646.2	4252.4
9	140	30	283.28	1650.9	4261.7
10	140	45	283.2	1652.1	4269.6

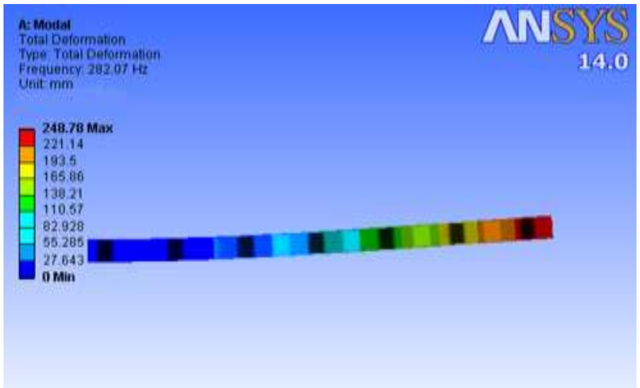

Fig -9: First Mode Shape for Healthy Honeycomb plate.

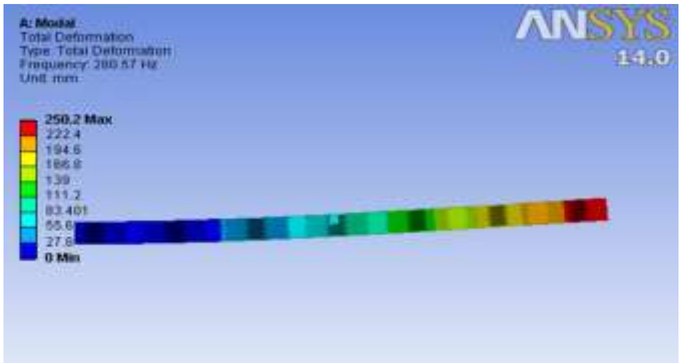

Fig -10: First Mode Shape for crack 100mm X-Direction and 15mm Y-direction

7. EXPERIMENTATION

In this test setup as shown in fig 11 FFT Analyzer is used to obtain the frequency response function of the specimen. It consists of the impact hammer and accelerometer for excitation of the specimen and collecting the frequency response. The specimen is Honeycomb structure plate which is fixed at support which is the rigid support used for supporting the different types of jobs. It is an I-section support with a clamping provided with the upper plate of the clamp attached with the nut and bolt arrangement. The total arrangement with FFT Analyzer is as shown in the fig 11 and fig 13.

The specimen which is made of aluminium material having two skin plates attached from top and bottom and the intermediate portion consists of the honeycomb core as shown in fig 12. The detail of the geometry of the honeycomb structure plate is as given in the table 4.

TABLE-4; Dimensions for the Honeycomb Structure Plate

Parameter	Dimension
Length (a)	200mm
Width (b)	75mm
Thickness of the skin (t)	0.5mm
Cell size (l)	3mm
Cell thickness (tc)	0.5mm
Core height (h)	9mm

Fig-11: FFT Analyzer

Fig-12: Specimen of Honeycomb Structure

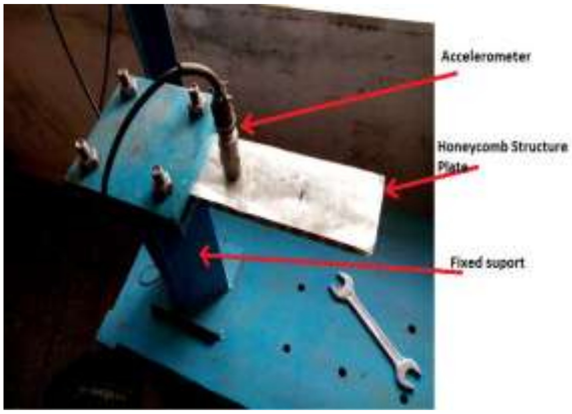

Fig-13: Test Setup.

Fig-14: Test Setup

7.1 Experimental Procedure

The manufactured honeycomb structured aluminium plates were tested with the one end fixed like cantilever beam model. The plate was supported on rigid I-section structure girder. The plate was excited with an impact hammer. The first three natural frequencies were measured for healthy plates (without crack). The crack was artificially created in the plates at different locations for the total 9 plates with varying distance.

Also the Honeycomb structure at the specific location was crushed where the crack was created. This was to achieve the delamination between the skin plate and the honeycomb plate. Then all models were excited separately and the first three natural frequencies of each plate were taken. The response of the each plate was measured with the help of the accelerometer placed on the plate during testing. The responses were acquired one at a time for each plate using the FFT Analyzer

8. RESULTS AND DISCUSSIONS

The modal frequency analysis carried out experimentally for the honeycomb structure plate. It's one end was fixed in the fixed structure. The first 3 natural frequencies were determined for all 9 plates including healthy plate. The results are given in the table 5. It is found that there is small deviation in modal frequencies of each plate. It is due to difference in crack location in each plate.

TABLE-5: Experimental Results

Case	Crack position X	Crack Position Y	Frequencies (Hz)		
	mm	mm	f1	f2	f3
1	Healthy		287	1671	4368
2	100	15	279	1693	4194
3	100	30	240	1632	4242
4	100	45	354	1650	4306
5	120	15	252	1655	4167
6	120	30	240	1671	4265
7	120	45	300	1674	4224
8	140	15	222	1719	4272
9	140	30	269	1691	4232
10	140	45	261	1610	4311

Ratio of Natural Frequencies

The results obtained from the experimental analysis for all cracked plates including the healthy plates with normalized ratio i.e. ratio of frequency of damaged plate to the frequency of healthy plate are shown in the following table's 6, 7, 8. It is observed that the first and second frequency is more affected as compared to the third frequency which is least affected since the nodal point of the third frequency at the center of the plate.

Table-6: Normalized Frequencies Mode I

First mode shape frequency ratio			
X\Y	15	30	45
100	0.972125436	0.836236924	1.233449476
120	0.87804978	0.836236934	1.045296267
140	0.773519264	0.93728223	0.909407666

Table-7: Normalized Frequencies Mode II

Second mode shape frequency ratio			
X\Y	15	30	45
100	1.013165869	0.976661682	0.987431675
120	0.990434895	1	1.001795332
140	1.028725214	1.011968881	0.963494913

Table-8: Normalized Frequencies Mode III

Third mode shape frequency ratio			
X\Y	15	30	45
100	0.960163835	0.971154846	0.985815861
120	0.953983516	0.976219414	0.967042967
140	0.978021978	0.968864469	0.986950549

Again the fig 14, 15, 16 shows the 3D plots of the frequency ratio of damage plate to healthy plate with the position of the damage in the plate i.e. the location X and Y. Also it shows the contours for the 3D plots for each of the graph. This was drawn with the help of the Design Expert 7.0 software which provided the exact detection of crack or the damage in the plate using the contour plots.

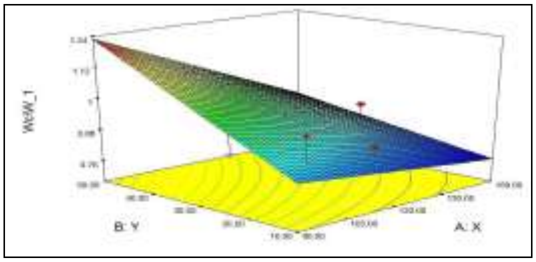

Fig-16: plot of frequency ratio versus the position of the damaged location for first mode shape

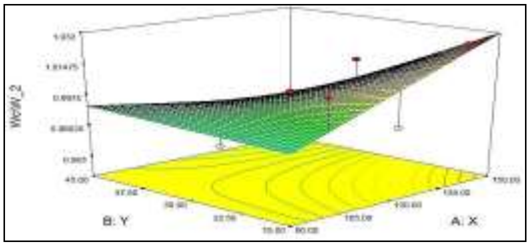

Fig-17: plot of frequency ratio versus the position of the damaged location for second mode shape

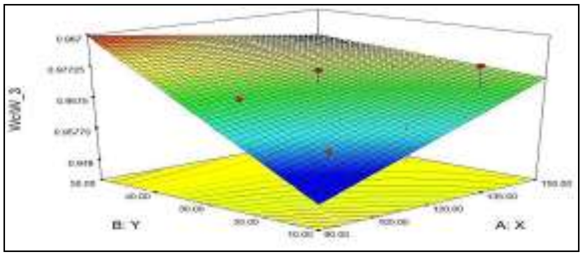

Fig-18: plot of frequency ratio versus the position of the damaged location for third mode shape

FFT Analyzer Spectrums

For example the spectrums obtained from FFT Analyzer are as below in Fig 17 which shows the FRF (Frequency Response function) spectrum analysis for the first 3 natural frequencies for damage location 100-15 in honeycomb structure plate.

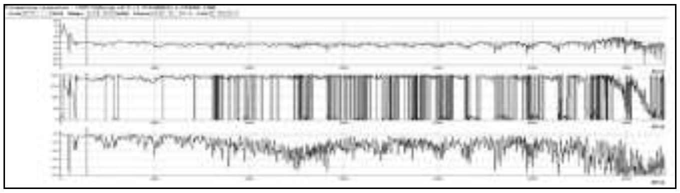

Fig-19: FRF spectrum for damage 100-15 honeycomb plate

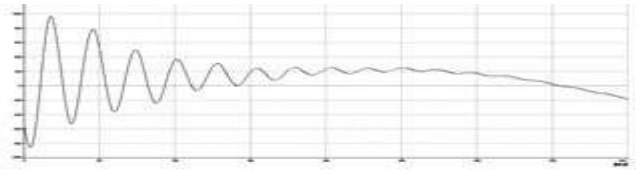

Fig-20: Time spectrum for damage 100-15 honeycomb plate

Similarly for other crack location can be obtained. Also Fig 18 is the time spectrum graph in which there is much variation up to 200sec and spectrum varies between 4.5 to -4.5 m/s2. And the fig 19 shows the graph of amplitude vs. frequency for same crack locations. The cursor in respective spectrum represents first natural frequency for the damage location

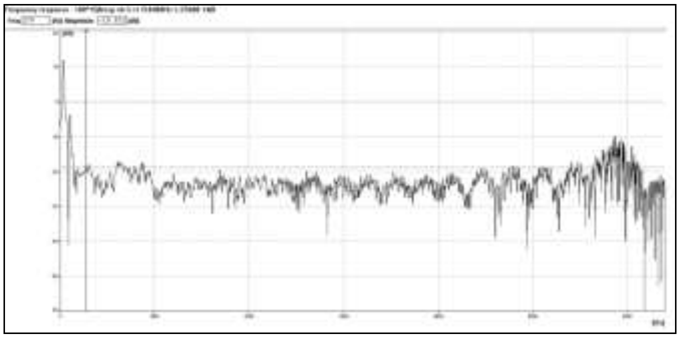

Fig-21: FRF amplitude spectrum for damage 100-15 honeycomb plate Detection of the Damage Location

For the locating the position of the damage the contour plots for the first three normalized natural frequency for experimental are plotted using Design Expert. Since two contours for first two natural frequencies cannot locate the exact location the third frequency contour is used for locating it. The intersections point for all three contour plots specifies the location of the damage. In the Fig 20 shows that 0.890559 is the normalized frequency ratio for first mode, 0.95784 for damage i.e. equal to X=100mm and Y=15mm

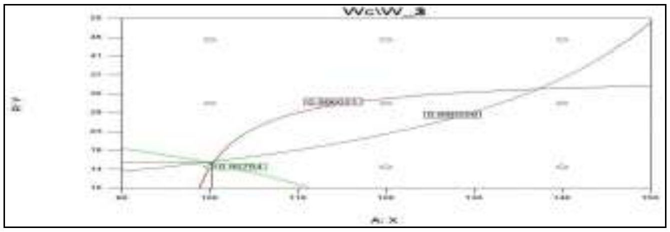

Fig-22: Contour plot for location X 100 Y15

When we are using the method of frequencies of contour plots for identification of damage or crack of such type of structure following steps should be followed for prediction of the unknown damage parameters:

1. Measure the first three frequencies

2. Normalization of the frequencies

3. Plotting of the contour graphs for different mode shapes on the same axes

4. Location of the point of intersection of the different contour lines

The point of intersections common to all the three modes indicates the damage length and width. This intersection will be unique due to the fact that any normalized crack. Frequency can be represented by governing equation that is dependent on damage length and width. Therefore a minimum of three curves is required to identify the two unknown parameters of damage/crack length and width.

9. CONCLUSIONS

In this study, an attempt has been made to detect presence and the location of defect in honeycomb plate using vibration measurement utilizing Fast Fourier Transform analyzer. The following conclusions are drawn

It indicated that the proposed technique can be effectively and appropriately applied for detection of defect in full scale composite structures (e.g., large FRP honeycomb sandwich structures) used for aerospace applications.

The locations of the damage for both damage configuration (i.e., the core–faceplate debonding and core crushing, respectively) can be identified properly using the contours plotted in Design Expert, while the magnitude of the damage can also be evaluated through the stiffness loss The location of the damage can be easily found out with the help of first three natural frequencies and mode shapes. By using frequency contour it is possible to find normalized crack location along with approximate crack location.

10. ACKNOWLEDGMENT

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REFERENCES

[1] Wahyu Lestari, PizhongQiao, "Damage detection of fiber-reinforced polymer honeycomb sandwich beams", 'Composite Structures', 2005, 67, 365–373.
[2] A.Boudjemai , M.H. Bouanane, Mankour, R. Amri, H. Salem, B. Chouchaoui, "MDA of Hexagonal Honeycomb Plates used forSpace Applications", 'World Academy of Science, Engineering and Technology', 2012, 66, 221-229.
[3] MissoumLakhadar, Djermane Mohammed, LabbaciBoudjemaa, "Damages detection in a composite structure by vibration analysis", 'Energy Procedia', 2013, 36, 888-897.
[4] A.V. Deokar, V.D. Wakchaure, "Experimental investigation of crack detection in cantilever beam using natural frequency as basic criterion", 2011, 382-481.

[5] H. Nahvi,M. Jabbari, “Crack Detection in beams using experimental modal data and finite element model”, 2005, 47, 1477-1497.
[6] J.T. Kim, “Crack Detection in beam type structures using frequency data”, 2003, 259, 145-160.
[7] Marta B. Rosales, Carlos P. Filipich, Fernando S. Buezas, “Crack Detection in beam type structures”, 2009, 31, 2257-2264.
[8] Edward Z. Moore, Jonathan M. Nichols, Kevin D. Murphy, “Model-based SHM: Demonstration of identification of crack in a thin plate using free vibration data”, 2012, 29, 284-295.
[9] Akhilesh Kumar, J.N.Mahto, “Experimental investigation of crack in aluminium cantilever beam using vibration monitoring technique”, 2014, 4, 39-49.
[10] Emil Manoach, Irina Trendafilova, “Large amplitude vibrations and damage detection of rectangular plates”, 2008, 315, 591-606.